Government of Canada | Gouvernement du Canada
Canadian Forestry Service | Service canadien des forêts

Volume and Biomass Yield Tables for Unthinnned Red Pine Plantations at the Petawawa National Forestry Institute

A.B. Berry

Information Report PI-X-32
Petawawa National Forestry Institute

86-0365/

VOLUME AND BIOMASS YIELD TABLES FOR UNTHINNED RED PINE PLANTATIONS AT THE PETAWAWA NATIONAL FORESTRY INSTITUTE

Information Report PI-X-32

A.B. Berry

Petawawa National Forestry Institute
Canadian Forestry Service
Department of the Environment
1984

©Minister of Supply and Services Canada 1984
Catalogue No. Fo46-11/32-1984E
ISSN 0706-1854
ISBN 0-662-13028-6

Additional copies of this publication can be obtained from:

Technical Information and Distribution Centre
Petawawa National Forestry Institute
Environment Canada
Chalk River, Ontario
K0J 1J0

Telephone 613 589-2880

Cette publication est aussi disponible en français sous le titre Tables de rendement en volume et en biomasse pour des plantations non éclaircies à l'Institut forestier National de Petawawa.

Contents

i	Abstract/Résumé
1	Introduction
1	Plantations
1	Methods
1	Terminology
2	Sample plots
2	Site index curves
3	Tree mortality and number of stems/ha
4	Basal area
4	Mean stand diameters
4	Stand volume
5	Biomass
5	Yield tables
6	Mean annual increment
6	Management implications
7	References
	Tables
8	1. Yield table for unmanaged red pine plantations (site index 15)
11	2. Yield table for unmanaged red pine plantations (site index 18)
14	3. Yield table for unmanaged red pine plantations (site index 21)
17	4. Yield table for unmanaged red pine plantations (site index 24)
20	5. Yield table for unmanaged red pine plantations (site index 27)
23	6. Age at which MAI is at a maximum
24	7. Percentages used to derive merchantable volume from total volume and merchantable stem plus bark biomass from total stem plus bark biomass
	Figures
25	1. Site index curves, at base age of 50 years from planting, for planted red pine.
26	2. Relationship of numbers of trees to dominant heights and initial spacing for planted red pine.
27	3. Diameter, basal area, total volume, and total biomass of planted red pine as affected by site index and spacing.

Abstract

Yield tables for high survival unthinned red pine plantations were updated, revised, and extended from 50 to 60 years. For the first time they show data on biomass. Tables present data from 20 to 60 years from planting, by 5-year age classes, for eight spacings and five site index classes. Each table shows the dominant height, average height, number of trees, mean dbh, total basal area, total volume, merchantable volume, biomass of total tree above ground, biomass of main stem including bark, and biomass of merchantable stem including bark.

Résumé

Les tables de rendement pour les plantations de pin rouge non éclaircies et à survie élevée ont été mises à jour, révisées et étendues de 50 à 60 ans. Elles incluent pour la première fois des données sur la biomasse. Les tables présentent les données pour la période de 20 à 60 ans après la plantation par classes d'âge de cinq ans, pour huit espacements et pour cinq classes d'indice de site. Chaque table donne la hauteur dominante, la hauteur moyenne, le nombre d'arbres, le diamètre moyen à la hauteur de poitrine, la surface terrière totale, le volume total, le volume marchand, la biomasse de la partie épigée totale, de la tige principale avec écorce et de la partie marchande avec écorce.

VOLUME AND BIOMASS YIELD TABLES FOR UNTHINNED RED PINE PLANTATIONS AT THE PETAWAWA NATIONAL FORESTRY INSTITUTE

INTRODUCTION

The present yield tables supersede previously published tables for plantation-grown red pine (Pinus resinosa Ait.) (Berry 1977, Stiell and Berry 1973).

The regression equations were revised and improved, and include additional remeasurement data from older plantations. The tables have been extended to include values to age 60 years from planting and show, for the first time, estimates of biomass in tonnes per hectare.

PLANTATIONS

The tables are based on data from 31 plantations totalling some 93 hectares located at the Petawawa National Forestry Institute, Chalk River, Ontario. They represent ages of 9 to 53 years from planting. The data are from 56 different sample plots ranging in size from 0.04 to 0.21 ha. The plots represent high survival, with virtually all mortality since stand establishment due to intertree competition.

Most of the planting was in evenly spaced rows, at approximately square spacings, in the range of 1.2 m to 4.3 m (4 feet to 14 feet). The planting sites were mainly old fields but included some burned-over areas. The principal soils were loamy or sandy tills and waterlaid sands, both often capped with windblown sand; lacustrine silts occurred occasionally. Site characteristics, plantation establishment, and juvenile growth of most of the plantations were described in detail by Stiell (1955).

METHODS

Terminology

This paper discusses stocking levels in terms of both number of trees per hectare and square spacing, which are the generally accepted terms used in plantation work. The equivalent values are as follows:

A.B. Berry is a research scientist at the Petawawa National Forestry Institute.

Manuscript approved for publication: October 1983.

Spacing class (m)		Trees per hectare	
Mid point	Range	Mid point	Range
1.25	1.13 - 1.37	6400	7900 - 5289
1.50	1.38 - 1.62	4444	5288 - 3787
1.75	1.63 - 1.87	3265	3786 - 2844
2.00	1.88 - 2.12	2500	2843 - 2215
2.50	2.38 - 2.62	1600	1772 - 1451
3.00	2.88 - 3.12	1111	1209 - 1024
3.50	3.38 - 3.62	816	877 - 761
4.00	3.88 - 4.12	625	665 - 588

In all calculations the spacing equivalent of number of trees per hectare was expressed to the nearest hundredth of a metre, e.g. 1520 trees/ha is equal to an average spacing of 2.56 x 2.56 m.

Sample plots

Data for the analysis were obtained from 56 sample plots in areas of uniformly high survival. Each plot was measured from one to seven times. Individual tree records (made possible by numbering and tagging each tree) were kept and stand tables were prepared at every measurement. The data on numbers of trees, average diameter, dominant height, basal area, and total volume were converted to metric units. The following are the range of values from plantation data:

Age (years from planting)	9 - 53
Trees/ha	489 - 6049
Equivalent spacing (m)	4.5 - 1.3
Average dbh (cm)	4.3 - 34.3
Dominant height (m)	4.1 - 26.1
Basal area (m^2/ha)	0.9 - 66.6
Total volume (m^3/ha)	3.8 - 631.9

The various parameters in the yield tables were individually related to height and spacing by regression methods, using the particular average values from each plot. Remeasurements from individual plots were treated as independent observations. The tables were then derived by appropriate substitution in the regression equations. These equations provided estimates for the required combinations of age, site, and spacing. This approach, therefore, models stand values at various stages of development rather than stand growth.

Site index curves

Nearly all the published site index curves are based on a total age of 50 years from seed. In the present study, because all data are being given in years from planting, it was decided that this should be the basis rather than total age.

Originally (Berry 1977) the dominant height/age data from all plots were used in deriving the base curve but, with the addition of new data for older age classes, it was found that the original guide curve was too high in the mid part. An inspection of the data revealed that data in this section were from medium and better sites. This tended to raise the central portion of the curve and drop it too rapidly after age 50. To correct this, only plots that covered a wide range in age were selected and, the following base curve was derived:

$$H = 0.5909A - 0.0025A^2 \quad (1)$$

where H = dominant height in m
A = age in years from planting.

A series of anamorphic site index curves, representing 3-m height classes at age 50 years from planting, were prepared and are shown in Figure 1.

Tree mortality and number of stems/ha

Mortality resulting from mutual competition is taken to be a function of increasing stature of individual trees. Relating mortality to stand height, therefore, is not only reasonable but has the advantage of incorporating the effects of both age and site.

The data from all plots for number of trees, dominant height, height growth, and mortality during each period, were combined and an expression relating mortality to a combination of stand density and dominant height was derived:

$$M = 0.0016X^2 - 0.1504X \quad (2)$$
$$R^2 = .757$$

where M = the number of trees dying with an increase of 3 m of dominant height
X = number of trees/ha x dominant height/100

This relationship is considered to be independent of age and site. There is a threshold in that no mortality from mutual competition would be expected until after crown closure has taken place; mortality will begin earlier in close-spaced stands than in those more widely spaced. A ceiling also probably exists beyond which a stand cannot maintain its density because of snow breakage. In the study area, for example, plantations established at 1.2-m spacing suffered severe damage of this type when they reached a dominant height of about 15 m. There is insufficient data available to predict when snow breaking might occur at different spacings but close-spaced stands cannot be projected indefinitely in the unthinned condition.

In order to produce numbers of trees over dominant height for each spacing class (Figure 2) the mortality regression was applied as follows. For each spacing class the regression was solved beginning with a low height and the initial planted number of trees, and with increasing height until the death of at least one tree was indicated. The number of trees was

reduced accordingly, the dominant height increased by 3 m, and a new mortality figure calculated. This procedure was continued until the maximum dominant height to be used at age 60 was reached.

Basal area

A stepwise regression was run with spacing and dominant height alone and in various combinations as the independent variables, and basal area per hectare as the dependent variable; the regression was forced through the origin. The equation derived was:

$$BA = 4.5749H/\sqrt{S} - 0.0263969H^2/\sqrt{S} \qquad (3)$$
$$R^2 = .992$$

where BA = basal area in m^2/ha
H = dominant height in m
S = average spacing between trees in m

With this regression the basal area for each cell of the yield tables was calculated based on the corresponding dominant height and average spacing.

Mean stand diameters

The basal area per hectare was divided by the number of trees to get the average basal area per tree. The diameter corresponding to this basal area per tree was then entered in the tables as the mean stand diameter.

In general it was found that 75 percent or more of the number of trees were within five contiguous 2-cm diameter classes centred about the class in which the mean stand diameter was located. Also, with closer spacing and decreasing average diameter, this percentage increased; in fact, in many cases over 90 percent of the trees were within this diameter range.

Stand volume

A step-wise regression was run with dominant height and spacing in various combinations as the independent variables, and total volume per hectare as the dependent variable. The resulting equation was:

$$V = -66.21233 + 0.97581(H/\sqrt[3]{S})^2 + 15.66002H/\sqrt[3]{S} + 0.09843H^2 \qquad (4)$$
$$R^2 = .978$$

where V = total volume m^3/ha
H = dominant height in m
S = average spacing in m

Metric merchantable volume tables were not available; therefore, the procedure followed was to use the percentage of merchantable cubic feet to total cubic feet per acre calculated previously, based on a top diameter of 4 in (10 cm) (Stiell and Berry 1973). Then, through graphical methods based on spacing and dominant height expressed in metric units, the merchantable volume in cubic metres was derived for each combination of spacing and height required by the yield tables. The percentages for each spacing and 1-m height are shown in Table 7.

Biomass

The term "total biomass" in this paper refers to the aboveground (ovendry) mass of all living red pine trees and includes stem wood, stem bark, branches, and needles. The total biomass per hectare was calculated using the equation developed by Alemdag and Stiell (1982):

$$OM = N\,[10.157 + 0.015686(d^2h) + 3960n^{-1} - 0.02891A] \qquad (5)$$
$$R^2 = 0.977$$

where OM = ovendry mass in kg/ha
N = number of trees present/ha
d = average breast height diameter in cm
h = average stand height in m
n = number of trees planted/ha
A = age in years from planting

An average basic wood density of 0.364 was applied to the total volume to arrive at the biomass of the stem, to which was added 8.2 percent of this value to get the biomass of the stem plus bark. These conversion factors were taken, respectively, from Stiell and Alemdag (1982) and Cody (1972).

The merchantable stem plus bark value was derived from the stem plus bark mass by applying the same percentage figures as were applied to total volume to arrive at merchantable volume.

In a thinning or harvesting operation for conventional products (roundwood and sawlogs) the residues available for fuel can be estimated by subtracting the merchantable mass from the total.

Yield tables

Yield tables are predictive and show the progression of stand development with age. Tables 1 to 5 show yields for five 3-m site index classes at base age of 50 years. For each site index class, values are shown at 5-year intervals, from 20 to 60 years, for eight initial planted spacings. The procedures for estimating the various parameters can be summarized as follows:

a. Dominant heights at given ages were read from the site index curves (Figure 1).

b. Average height was obtained from the following regression:

$$Y = 0.9767X - 0.9206$$
$$R^2 = .997$$

where X = dominant height in m
Y = average height in m

c. [illegible] per hectare were read from the numbers/height curve [illegible] (Figure 2).

d. The basal areas were calcualted from regression (3).

e. The mean dbh to the nearest tenth of a cm was calculated from the basal area/ha and numbers of trees found in c and d.

f. Total volumes were calculated from regression (4).

g. The merchantable volume was calculated as a percentage of the total volume (Table 7).

h. The total tree biomass was calculated for each age, site, and spacing combination by substituting the respective stand values in regression (5).

i. The biomass of total stem plus bark was calculated from the total volume by applying an average wood density factor and adding a percentage of this biomass for bark.

j. The biomass for merchantable stem plus bark was taken as a percentage of the total stem plus bark biomass (Table 7).

Most of the yield table values are based on data that fall within the limits of spacing and height. Bracketing of data in tables indicate that these values are extrapolations with respect to spacing and/or dominant height.

Figure 3 shows how diameter, basal area, total volume, and total biomass vary with site index class and spacing.

Mean annual increment

The ages at which mean annual increment is at a maximum for volume and mass were determined by inspection of the tables and are shown in Table 6. Generally, for any given spacing, MAI culminates earlier on better sites, and for any given site class this is directly related to spacing (i.e. the closer spacings reach a maximum sooner than wider spacings).

Management implications

1. For a given age, wider spacings give larger average dbh, total volume, and mass per tree but lower per hectare values.

2. MAI for merchantable volume (except for three cells) and mass of merchantable stem plus bark had not reached a maximum by age 60. This implies that complete harvesting of the stand should not be contemplated until 60 years or later from planting.

3. Planting too close (1.3 m or less) makes thinning impractical and leaves stands vulnerable to heavy loss from snow damage before merchantable material is available. At the other end of the scale (4.0 m or wider) trees develop such large branches as to disqualify them as useful sources of poles or sawlogs (Stiell 1966). Within these limits, say 1.5 m to 3.0 m, choice of spacing is governed by the end product desired, and whether or not a market exists for thinnings. If the object is to grow biomass or pulpwood a closer spacing is indicated; if it is large dimension stock, then a wider one should be chosen.

REFERENCES

Alemday, I.S.; Stiell, W.M. 1982. Spacing and age effects on biomass production in red pine plantations. For. Chron. 58: 220-224.

Berry, A.B. 1977. Metric yield tables based on site class and spacing for unthinned red pine plantations at the Petawawa Forest Experiment Station. Can. Dep. Environ., Can. Forest. Serv., Petawawa Forest Exp. Stn., Inf. Rep. PS-X-65. 17 p.

Cody, J.B. 1972. Some wood characteristics of plantation grown red pine in New York State. State Univ., Coll. For. at Syracuse Univ., Appl. For. Res. Inst., AFRI Res. Rep. No. 9. 19 p.

Stiell, W.M. 1955. The Petawawa plantations. Can. Dep. North. Aff. Nat. Res., For. Br., Res. Div. Tech. Note 21. 46 p.

Stiell, W.M. 1966. Red pine crown development in relation to spacing. Can. Dep. For., Pub. No. 1145.

Stiell, W.M.; Berry, A.B. 1973. Yield of unthinned red pine plantations at the Petawawa Forest Experiment Station. Can. Dep. Environ., Can. For. Serv., Publ. No. 1320. 16 p.

Table 1. Yield table for unmanaged red pine plantations (site index 15)

Age from planting	Dominant height	Average height	Planted spacing	Trees per ha	Mean d.b.h.	Basal area/ha	Volume/ha		Biomass/ha		
							Total	Merch.	Total tree	Total stem & bark	Merch. stem & bark
years	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	7.0	5.9	1.25	6335	7.4	27.4	81	14	97	32	5
			1.50	4420	8.5	25.1	71	18	76	28	7
			1.75	3255	9.5	23.2	63	21	62	25	8
			2.00	2498	10.5	21.7	56	22	53	22	9
			2.50	1600	12.4	19.4	45	22	42	18	9
			3.00	1111	14.3	17.7	38	20	36	15	8
			3.50	816	16.0	16.4	32	17	31	13	7
			4.00	625	17.7	15.4	27	15	28	11	6
25	8.5	7.4	1.25	6250	8.2	32.9	125	34	112	49	13
			1.50	4380	9.4	30.1	110	40	90	43	15
			1.75	3238	10.5	27.9	100	43	76	39	17
			2.00	2491	11.6	26.1	91	45	66	36	18
			2.50	1600	13.6	23.4	77	45	53	30	17
			3.00	1111	15.6	21.4	67	43	46	26	17
			3.50	816	17.6	19.8	59	40	41	23	15
			4.00	625	19.4	18.5	53	36	37	21	14
30	10.0	8.8	1.25	6100	8.9	38.1	171	63	127	67	25
			1.50	4320	10.2	35.0	154	69	106	61	27
			1.75	3207	11.3	32.4	140	73	90	55	29
			2.00	2475	12.5	30.4	129	74	80	51	29
			2.50	1597	14.7	27.3	112	74	66	44	29
			3.00	1111	16.9	24.9	99	70	58	39	28
			3.50	816	19.0	23.0	89	65	52	35	26
			4.00	625	21.0	21.6	81	61	48	32	24

35	11.3	10.1	1.25	5910	9.6	42.4	213	96	144	84	38
			1.50	4215	10.8	38.9	193	100	120	76	40
			1.75	3165	12.1	36.2	177	103	106	70	41
			2.00	2454	13.3	34.0	164	102	95	65	40
			2.50	1592	15.6	30.5	144	99	80	57	39
			3.00	1110	17.9	27.9	129	97	70	51	38
			3.50	816	20.1	25.8	117	90	64	46	35
			4.00	625	22.2	24.2	107	85	58	42	33
40	12.6	11.4	1.25	5660	10.2	46.3	257	131	160	101	52
			1.50	4110	11.5	42.8	235	134	138	93	53
			1.75	3116	12.8	40.0	217	135	123	85	53
			2.00	2427	14.0	37.5	202	133	111	80	53
			2.50	1584	16.5	33.7	178	130	95	70	51
			3.00	1109	18.8	30.9	161	126	84	63	49
			3.50	816	21.1	28.6	147	119	76	58	47
			4.00	625	23.3	26.7	135	111	70	53	43
45	13.9	12.7	1.25	5378	10.9	50.2	303	173	178	119	68
			1.50	3965	12.2	46.4	278	172	156	109	68
			1.75	3045	13.5	43.5	258	170	141	102	67
			2.00	2388	14.8	40.9	241	166	129	95	66
			2.50	1572	17.3	36.8	215	163	112	85	65
			3.00	1105	19.7	33.7	194	155	99	76	61
			3.50	816	22.1	31.3	178	148	91	70	58
			4.00	625	24.4	29.2	165	139	84	65	55
50	15.0	13.7	1.25	5100	11.5	53.0	341	208	193	134	82
			1.50	3835	12.8	49.4	316	205	172	124	81
			1.75	2970	14.1	46.3	295	204	156	116	80
			2.00	2350	15.4	43.7	276	199	144	109	78
			2.50	1558	17.9	39.4	247	193	125	97	76
			3.00	1101	20.4	36.1	224	184	112	88	72
			3.50	815	22.9	33.5	206	175	103	81	69
			4.00	625	25.3	31.3	191	164	95	75	64

55	16.1	14.8	(1.25	4820	12.1	55.7	381	244	208	150	96)
			1.50	3690	13.4	52.0	354	237	189	139	93
			1.75	2888	14.7	49.0	332	236	173	131	93
			2.00	2305	16.0	46.3	312	231	160	123	91
			2.50	1542	18.6	41.8	279	223	141	110	88
			3.00	1096	21.1	38.4	255	212	127	100	83
			3.50	814	23.6	35.7	235	202	116	93	80
			4.00	625	26.1	33.4	219	191	108	86	75
60	17.0	15.7	(1.25	4570	12.7	57.7	413	273	223	163	108)
			1.50	3560	13.9	54.1	386	266	203	152	105
			1.75	2808	15.2	51.0	362	264	187	143	104
			2.00	2260	16.5	48.4	342	260	174	135	103
			2.50	1526	19.1	43.8	308	249	154	121	98
			3.00	1091	21.7	40.3	281	236	140	111	93
			3.50	812	24.2	37.4	260	226	128	102	89
			4.00	625	26.7	35.1	242	211	119	95	83

Table 2. Yield table for unmanaged red pine plantations (site index 18)

Age from planting	Dominant height	Average height	Planted spacing	Trees per ha	Mean d.b.h.	Basal area/ha	Volume/ha		Biomass/ha		
							Total	Merch.	Total tree	Total stem & bark	Merch. stem & bark
years	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	8.4	7.3	1.25	6260	8.1	32.6	122	33	111	48	13
			1.50	4383	9.3	29.8	108	38	89	43	15
			1.75	3240	10.4	27.6	97	42	75	38	16
			2.00	2492	11.5	25.9	89	44	66	35	17
			2.50	1600	13.6	23.1	75	44	53	30	17
			3.00	1111	15.6	21.1	65	42	46	26	17
			3.50	816	17.5	19.5	57	38	40	22	15
			4.00	625	19.3	18.3	51	35	37	20	14
25	10.2	9.0	1.25	6083	9.0	38.8	177	67	131	70	27
			1.50	4314	10.3	35.6	160	74	109	63	29
			1.75	3200	11.5	33.0	145	77	94	57	30
			2.00	2472	12.6	31.0	134	78	83	53	31
			2.50	1596	14.9	27.8	117	77	69	46	30
			3.00	1111	17.0	25.4	104	75	60	41	30
			3.50	816	19.1	23.5	93	69	54	37	27
			4.00	625	21.2	22.0	85	65	50	33	25
30	12.0	10.8	1.25	5780	9.9	44.5	236	116	153	93	46
			1.50	4160	11.2	41.0	215	118	130	85	47
			1.75	3143	12.5	38.3	199	121	116	78	48
			2.00	2441	13.7	36.0	185	118	104	73	47
			2.50	1588	16.1	32.3	162	115	88	64	45
			3.00	1110	18.4	29.5	146	111	80	58	44
			3.50	816	20.6	27.3	133	105	70	52	41
			4.00	625	22.8	25.5	122	99	65	48	39

35	13.6	12.4	1.25	5450	10.7	49.3	292	164	175	115	64
			1.50	4008	12.0	45.6	268	163	152	106	65
			1.75	3065	13.3	42.6	248	161	137	98	64
			2.00	2400	14.6	40.1	232	160	125	91	63
			2.50	1576	17.1	36.1	206	155	108	81	61
			3.00	1106	19.5	33.0	186	149	96	73	58
			3.50	816	21.9	30.6	171	140	88	67	55
			4.00	625	24.2	28.7	158	133	81	62	52
40	15.2	13.9	1.25	5050	11.6	53.4	348	212	197	137	84
			1.50	3810	12.9	49.8	323	210	176	127	83
			1.75	2958	14.2	46.8	301	208	160	119	82
			2.00	2343	15.5	44.1	282	203	148	111	80
			2.50	1556	18.0	39.8	252	197	128	99	77
			3.00	1100	20.6	36.5	229	188	116	90	74
			3.50	815	23.0	33.9	211	179	105	83	71
			4.00	625	25.4	31.7	196	169	98	77	66
45	16.6	15.3	(1.25	4690	12.4	56.8	399	259	218	157	102)
			1.50	3610	13.7	53.3	372	253	198	147	100
			1.75	2845	15.0	50.2	349	251	182	137	99
			2.00	2283	16.3	47.5	329	247	169	130	97
			2.50	1534	18.9	43.0	295	236	149	116	93
			3.00	1093	21.5	39.5	269	226	135	106	89
			3.50	813	24.0	36.7	248	213	124	98	84
			4.00	625	26.4	34.3	231	201	114	91	79
50	18.0	16.7	(1.25	4290	13.3	59.7	448	305	239	176	120)
			1.50	3390	14.5	56.3	421	299	219	166	118
			1.75	2720	15.8	53.3	397	298	205	156	117
			2.00	2205	17.1	50.6	376	290	192	148	114
			2.50	1506	19.7	45.9	339	280	170	134	110
			3.00	1083	22.3	42.3	311	264	154	122	104
			3.50	809	24.9	39.3	288	251	142	113	98
			4.00	624	27.4	36.9	269	237	132	106	93

55	19.3	17.9	(1.25	3910	14.2	62.0	495	351	257	195	138)
			1.50	3170	15.4	58.8	467	346	241	184	136
			1.75	2590	16.6	56.0	444	342	226	175	135
			2.00	2125	17.9	53.3	421	333	213	166	131
			2.50	1474	20.5	48.7	382	317	190	150	124
			3.00	1070	23.1	44.9	351	302	173	138	119
			3.50	805	25.7	41.8	326	287	160	128	113
			4.00	624	28.3	39.2	305	271	150	120	107
60	20.4	19.0	(1.25	3630	15.0	63.9	534	390	276	210	153)
			1.50	2990	16.1	60.9	507	385	259	200	152
			1.75	2475	17.3	58.1	483	382	245	190	150
			2.00	2055	18.5	55.4	459	372	230	181	147
			2.50	1445	21.2	50.8	419	356	209	165	140
			3.00	1058	23.8	47.0	387	337	191	152	132
			3.50	800	26.4	43.8	359	320	177	141	125
			4.00	622	29.0	41.1	337	303	165	133	120

Table 3. Yield table for unmanaged red pine plantations (site index 21)

Age from planting	Dominant height	Average height	Planted spacing	Trees per ha	Mean d.b.h.	Basal area/ha	Volume/ha		Biomass/ha		
							Total	Merch.	Total tree	Total stem & bark	Merch. stem & bark
years	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	9.8	8.7	1.25	6130	8.8	37.4	164	59	127	65	23
			1.50	4330	10.0	34.3	148	65	104	58	26
			1.75	3210	11.2	31.8	134	68	90	53	27
			2.00	2478	12.4	29.8	124	59	80	49	27
			2.50	1598	14.6	26.8	107	70	66	42	27
			3.00	1111	16.7	24.4	95	66	57	37	26
			3.50	816	18.8	22.6	85	62	51	33	24
			4.00	625	20.8	21.1	77	58	47	30	22
25	11.9	10.7	1.25	5800	9.9	44.3	233	114	154	92	45
			1.50	4165	11.2	41.0	212	117	131	83	46
			1.75	3145	12.4	38.0	196	118	115	77	46
			2.00	2442	13.6	35.7	182	116	103	72	46
			2.50	1589	16.0	32.0	160	114	87	63	45
			3.00	1110	18.3	29.3	143	109	77	56	43
			3.50	816	20.6	27.1	130	103	70	51	40
			4.00	625	22.7	25.4	120	96	64	47	38
30	14.0	12.8	1.25	5360	10.9	50.3	306	174	181	121	69
			1.50	3960	12.3	46.7	281	174	161	111	69
			1.75	3040	13.5	43.8	262	176	143	103	69
			2.00	2387	14.8	41.1	244	171	131	96	67
			2.50	1571	17.3	37.1	217	165	113	85	65
			3.00	1105	19.8	33.9	197	158	101	78	62
			3.50	815	22.2	31.5	180	149	92	71	59
			4.00	625	24.5	29.4	167	140	85	66	55

35	15.9	14.6	(1.25	4860	12.0	55.2	374	236	208	147	93)
			1.50	3710	13.3	51.6	347	232	188	137	92
			1.75	2900	14.6	48.4	324	230	172	128	91
			2.00	2310	15.9	45.8	305	226	159	120	89
			2.50	1545	18.5	41.5	274	216	139	108	85
			3.00	1097	21.0	38.0	249	207	125	98	81
			3.50	814	23.5	35.3	229	197	114	90	77
			4.00	625	25.9	33.0	213	185	106	84	73
40	17.7	16.4	(1.25	4370	13.1	59.2	439	299	235	173	118)
			1.50	3440	14.4	55.8	411	292	218	162	115
			1.75	2745	15.6	52.6	387	286	200	152	112
			2.00	2225	16.9	49.9	366	282	187	144	111
			2.50	1513	19.5	45.4	330	271	165	130	107
			3.00	1086	22.1	41.8	302	257	150	119	101
			3.50	810	24.7	38.8	279	243	138	110	96
			4.00	624	27.2	36.4	261	230	128	103	91
45	19.4	18.0	(1.25	3880	14.3	62.1	497	358	261	196	141)
			1.50	3160	15.4	59.1	472	349	242	186	138
			1.75	2580	16.6	56.2	447	344	227	176	136
			2.00	2120	17.9	53.5	425	340	214	167	134
			2.50	1473	20.5	48.8	385	323	191	152	128
			3.00	1069	23.2	45.1	354	304	176	139	120
			3.50	805	25.8	42.0	329	290	162	130	114
			4.00	623	28.4	39.4	308	274	151	121	108
50	21.0	19.6	(1.25	3470	15.4	64.8	555	411	285	219	162)
			1.50	2895	16.5	61.9	529	402	270	208	158
			1.75	2409	17.7	59.1	504	398	256	198	156
			2.00	2015	18.9	56.5	481	394	242	189	155
			2.50	1428	21.5	51.9	440	374	219	173	147
			3.00	1051	24.1	48.1	407	358	201	160	141
			3.50	797	26.8	44.9	378	336	187	149	133
			4.00	621	29.4	42.2	355	320	174	140	126

55	22.5	21.1	(1.25	3070	16.6	66.7	607	461	308	239	182)
			1.50	2650	17.6	64.3	584	456	297	230	179
			1.75	2243	18.7	61.7	559	453	282	220	178
			2.00	1910	19.9	59.2	535	444	270	211	175
			2.50	1381	22.4	54.6	492	423	245	194	167
			3.00	1031	25.0	50.8	457	402	226	180	158
			3.50	788	27.7	47.5	426	383	211	168	151
			4.00	618	30.3	44.7	401	361	197	158	142
60	23.8	22.3	(1.25	2750	17.7	68.0	649	506	326	256	200)
			(1.50	2440	18.6	66.1	630	504	318	248	198)
			1.75	2085	19.7	63.5	604	495	303	238	195
			2.00	1810	20.8	61.3	583	490	292	230	193
			2.50	1338	23.3	56.8	539	469	269	212	184
			3.00	1010	25.8	52.9	501	446	247	197	175
			3.50	778	28.5	49.6	469	422	231	185	167
			4.00	614	31.1	46.7	441	401	217	174	158

Table 4. Yield table for unmanaged red pine plantations (site index 24)

Age from planting	Dominant height	Average height	Planted spacing	Trees per ha	Mean d.b.h.	Basal area/ha	Volume/ha		Biomass/ha		
							Total	Merch.	Total tree	Total stem & bark	Merch. stem & bark
years	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	11.1	9.9	1.25	5940	9.5	41.7	206	91	141	81	36
			1.50	4242	10.7	38.3	187	95	120	74	38
			1.75	3177	12.0	35.7	172	98	105	68	39
			2.00	2459	13.2	33.4	159	97	94	63	38
			2.50	1594	15.5	30.1	139	96	79	55	38
			3.00	1110	17.7	27.4	124	92	69	49	36
			3.50	816	19.9	25.4	113	87	62	45	35
			4.00	625	22.0	23.8	103	80	57	41	32
25	13.6	12.4	1.25	5450	10.7	49.3	292	164	176	115	64
			1.50	4008	12.0	45.6	268	163	154	106	65
			1.75	3065	13.3	42.6	248	161	138	98	64
			2.00	2400	14.6	40.1	232	160	126	91	63
			2.50	1576	17.1	36.1	206	155	108	81	61
			3.00	1106	19.5	33.0	186	149	96	73	58
			3.50	816	21.9	30.6	171	140	88	67	55
			4.00	625	24.2	28.7	158	133	81	62	52
30	15.9	14.6	1.25	4860	12.0	55.2	374	236	208	147	93
			1.50	3710	13.3	51.6	347	232	188	137	92
			1.75	2900	14.6	48.4	324	230	172	128	91
			2.00	2310	15.9	45.8	305	226	159	120	89
			2.50	1545	18.5	41.5	274	216	139	108	85
			3.00	1097	21.0	38.0	249	207	125	98	81
			3.50	814	23.5	35.3	229	197	114	90	77
			4.00	625	25.9	33.0	213	185	106	84	73

35	18.1	16.8	(1.25	4250	13.4	60.0	453	308	243	178	121)
			1.50	3370	14.6	56.5	425	306	223	167	120
			1.75	2710	15.9	53.5	401	301	209	158	118
			2.00	2200	17.1	50.8	379	292	193	149	115
			2.50	1505	19.8	46.2	343	281	173	135	111
			3.00	1082	22.4	42.5	314	267	157	124	105
			3.50	809	24.9	39.5	291	253	144	115	100
			4.00	624	27.5	37.1	271	238	134	107	94
40	20.2	18.8	(1.25	3680	14.8	63.6	527	385	273	208	152)
			1.50	3020	16.0	60.5	500	375	258	197	148
			1.75	2500	17.1	57.7	476	371	241	187	146
			2.00	2070	18.4	55.0	453	367	229	178	144
			2.50	1452	21.0	50.4	413	347	205	163	137
			3.00	1060	23.7	46.6	380	331	189	150	130
			3.50	801	26.3	43.5	353	314	174	139	124
			4.00	622	28.9	40.8	331	298	163	130	117
45	22.2	20.8	(1.25	3160	16.4	66.4	597	454	307	235	179)
			1.50	2700	17.4	63.9	573	447	293	226	176
			1.75	2280	18.5	61.3	548	444	278	216	175
			2.00	1935	19.7	58.8	525	436	265	207	172
			2.50	1392	22.2	54.1	481	414	240	189	162
			3.00	1035	24.9	50.2	446	392	222	176	155
			3.50	790	27.5	46.9	416	374	206	164	148
			4.00	619	30.1	44.2	391	352	192	154	139
50	24.0	22.5	(1.25	2720	17.9	68.3	657	512	333	259	202)
			(1.50	2410	18.7	66.2	636	509	321	250	200)
			1.75	2076	19.8	63.9	613	503	308	241	198
			2.00	1798	29.9	61.6	590	496	296	232	195
			2.50	1332	23.4	57.1	546	475	272	215	187
			3.00	1008	25.9	53.3	508	452	251	200	178
			3.50	777	28.6	49.9	476	428	235	187	168
			4.00	613	31.3	47.1	448	408	221	176	160

55	25.7	24.2	(1.25	2380	19.3	69.9	715	572	358	282	226)
			(1.50	2135	20.2	68.1	696	571	351	274	225)
			1.75	1880	21.1	65.9	672	564	336	265	223
			2.00	1665	22.1	64.0	652	561	326	257	221
			2.50	1273	24.5	59.8	609	536	304	240	211
			3.00	977	27.0	56.0	569	512	282	224	202
			3.50	762	29.7	52.6	534	486	265	210	191
			4.00	607	32.3	49.7	504	459	249	198	180
60	27.2	25.6	(1.25	2120	20.7	71.2	766	628	384	302	248)
			(1.50	1920	21.5	69.5	747	620	374	294	244)
			1.75	1735	22.3	67.7	727	618	363	286	243
			2.00	1550	23.3	65.8	707	615	353	278	242
			2.50	1211	25.5	61.9	664	584	329	262	231
			3.00	948	28.0	58.2	623	561	310	245	220
			3.50	747	30.6	54.8	587	534	291	231	210
			4.00	599	33.2	51.9	555	505	276	219	199

Table 5. Yield table for unmanaged red pine plantations (site index 27)

Age from planting	Dominant height	Average height	Planted spacing	Trees per ha	Mean d.b.h.	Basal area/ha	Volume/ha		Biomass/ha		
							Total	Merch.	Total tree	Total stem & bark	Merch. stem & bark
years	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	12.5	11.3	1.25	5680	10.2	46.0	253	129	163	100	51
			1.50	4116	11.5	42.5	231	132	140	91	52
			1.75	3120	12.7	39.7	214	133	123	84	52
			2.00	2430	14.0	37.2	199	129	112	78	51
			2.50	1585	16.4	33.5	176	127	95	69	50
			3.00	1109	18.8	30.6	158	122	84	62	48
			3.50	816	21.0	28.4	144	115	76	57	46
			4.00	625	23.2	26.5	133	109	70	52	43
25	15.3	14.0	1.25	5015	11.7	53.7	352	215	201	139	85
			1.50	3795	13.0	50.1	326	212	180	128	83
			1.75	2950	14.2	47.0	304	210	162	120	83
			2.00	2338	15.5	44.4	285	205	149	112	81
			2.50	1555	18.1	40.0	255	199	130	100	78
			3.00	1100	20.6	36.7	232	190	117	91	75
			3.50	815	23.1	34.1	214	182	107	84	71
			4.00	625	25.5	31.9	198	170	99	78	67
30	17.9	16.6	1.25	4310	13.3	59.6	446	303	241	176	120
			1.50	3405	14.5	56.2	418	297	221	165	117
			1.75	2725	15.7	53.0	393	295	204	155	116
			2.00	2210	17.0	50.3	372	286	190	147	113
			2.50	1508	19.6	45.7	336	276	169	132	108
			3.00	1084	22.2	42.1	308	262	153	121	103
			3.50	809	24.8	39.1	285	248	141	112	97
			4.00	624	27.4	36.7	266	234	132	105	92

35	20.4	19.0	(1.25	3630	15.0	63.9	534	390	279	210	153)
			1.50	2990	16.1	60.9	507	385	261	200	152
			1.75	2475	17.3	58.1	483	382	246	190	150
			2.00	2055	18.5	55.4	459	372	232	181	147
			2.50	1445	21.2	50.8	419	356	210	165	140
			3.00	1058	23.8	47.0	387	337	192	152	132
			3.50	800	26.4	43.8	359	320	177	141	125
			4.00	622	29.0	41.1	337	303	166	133	120
40	22.8	21.3	(1.25	2980	16.9	67.0	616	474	313	243	187)
			1.50	2590	17.8	64.7	594	469	300	234	185
			1.75	2195	19.0	62.1	569	461	287	224	181
			2.00	1885	20.1	59.7	547	454	274	215	178
			2.50	1370	22.6	55.1	503	433	250	198	170
			3.00	1026	25.2	51.3	467	411	231	184	162
			3.50	785	27.9	47.9	436	392	215	172	155
			4.00	617	30.5	45.1	410	369	201	161	145
45	24.9	23.4	(1.25	2540	18.6	69.3	689	544	347	271	214)
			(1.50	2260	19.5	67.3	668	541	337	263	213)
			1.75	1970	20.5	65.0	645	535	324	254	211
			2.00	1725	21.5	62.8	622	529	311	245	208
			2.50	1300	24.0	58.6	579	504	290	228	198
			3.00	992	26.5	54.7	540	481	268	213	190
			3.50	770	29.2	51.4	507	456	252	200	180
			4.00	610	31.8	48.5	478	435	236	188	171
50	27.0	25.5	(1.25	2145	20.5	71.0	758	614	381	299	242)
			(1.50	1945	21.3	69.2	739	613	372	291	242)
			(1.75	1754	22.1	67.5	720	612	360	284	241)
			(2.00	1562	23.1	65.6	699	608	349	275	239)
			(2.50	1220	25.4	61.7	656	577	328	258	227)
			(3.00	951	27.9	57.9	616	554	308	243	219)
			(3.50	749	30.5	54.6	580	528	289	228	207)
			(4.00	600	33.1	51.6	549	500	272	216	197)

55	28.9	27.3	(1.25	1840	22.3	72.2	821	681	409	323	268)
			(1.50	1700	23.0	70.7	804	675	401	317	266)
			(1.75	1555	23.8	69.1	785	667	392	309	263)
			(2.00	1415	24.7	67.5	767	667	384	302	262)
			(2.50	1140	26.7	64.0	727	640	361	286	252)
			(3.00	909	29.1	60.5	686	617	341	270	243)
			(3.50	728	31.6	57.2	648	590	321	255	232)
			(4.00	589	34.3	54.3	615	560	306	242	220)
60	30.7	29.1	(1.25	1600	24.1	73.1	880	739	439	347	291)
			(1.50	1505	24.7	72.0	866	736	433	341	290)
			(1.75	1410	25.3	70.9	853	734	426	336	289)
			(2.00	1290	26.2	69.3	834	734	417	328	289)
			(2.50	1068	28.1	66.1	794	707	397	313	279)
			(3.00	866	30.4	62.7	753	678	376	297	267)
			(3.50	704	32.8	59.5	715	651	355	282	257)
			(4.00	577	35.4	56.7	681	627	339	268	247)

Table 6. Age at which MAI is at a maximum

		Spacing (m)							
	SI	1.25	1.50	1.75	2.00	2.50	3.00	3.50	4.00
Total Volume	15	55	55	55	-	-	-	-	-
	18	55	55	55	55	-	-	-	-
	21	50	55	55	55	-	-	-	-
	24	45	45	50	55	55	-	-	-
	27	40	40	50	50	-	-	-	-
Merchantable Volume	15	-	-	-	-	-	-	-	-
	18	-	-	-	-	-	-	-	-
	21	-	-	-	-	-	-	-	-
	24	-	55	-	-	55	-	-	-
	27	55	-	-	-	-	-	-	-
Total Biomass	15	20	20	55	55	-	-	-	-
	18	20	40	50	55	-	-	-	-
	21	20	40	55	55	-	-	-	-
	24	20	45	45	55	55	-	-	-
	27	20	40	45	55	-	-	-	-
Biomass of total stem plus bark	15	55				-	-	-	-
	18	55	55	55	55	-	-	-	-
	21	50	55	55	55	-	-	-	-
	24	45	45	50	55	-	-	-	-
	27	40	40	50	50	-	-	-	-
Biomass of merchantable stem plus bark	15	-	-	-	-	-	-	-	-
	18	-	-	-	-	-	-	-	-
	21	-	-	-	-	-	-	-	-
	24	-	55	-	-	-	55	-	-
	27	55	50	50	50	-	-	-	-

Table 7. Percentages used to derive merchantable volume from total volume and merchantable stem plus bark biomass from total stem plus bark biomass

Dominant height	Planted spacing m							
	1.25	1.50	1.75	2.00	2.50	3.00	3.50	4.00
	Percent							
7	17	25	33	40	49	53	54	56
8	24	33	40	47	55	62	64	65
9	31	40	46	52	62	67	70	71
10	37	45	52	57	66	71	73	75
11	43	50	57	61	69	74	76	78
12	49	55	61	64	71	76	79	81
13	53	59	64	67	74	78	81	83
14	57	62	67	70	76	80	83	84
15	61	65	69	72	78	82	85	86
16	64	67	71	74	79	83	86	87
17	66	69	73	76	81	84	87	87
18	68	71	75	77	82	85	87	88
19	71	73	77	79	83	86	88	89
20	73	75	78	80	84	87	89	89
21	74	76	79	82	85	88	89	90
22	76	78	81	83	86	88	90	90
23	77	79	82	84	86	89	90	90
24	78	80	82	84	87	89	90	91
25	79	81	83	85	87	89	91	91
26	80	82	84	86	88	90	91	91
27	81	83	85	87	88	90	91	91
28	82	84	85	87	88	90	91	91
29	83	85	86	87	88	90	91	92
30	84	85	86	88	89	90	91	92

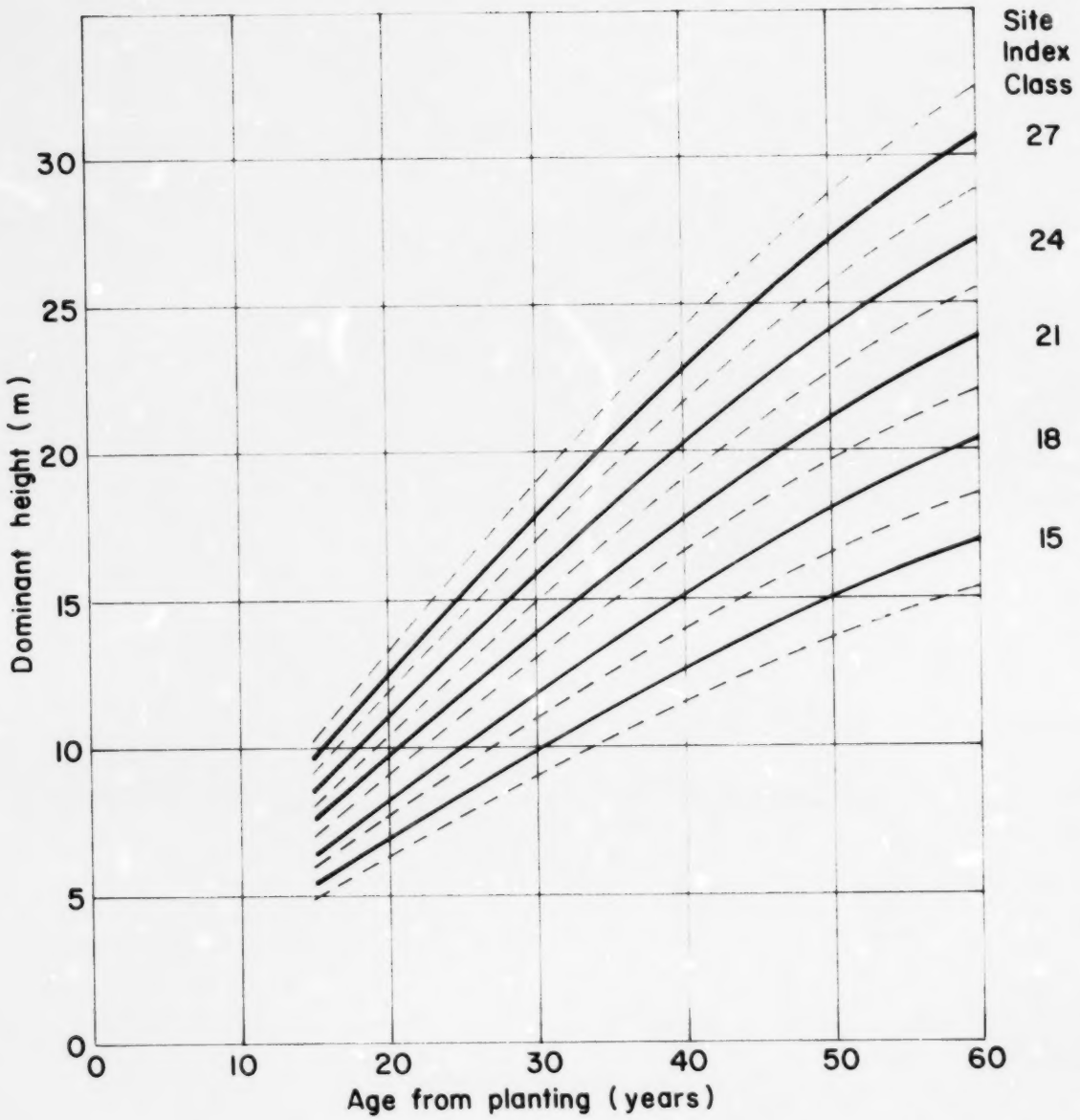

Figure 1. Site index curves, at base age of 50 years from planting, for planted red pine.

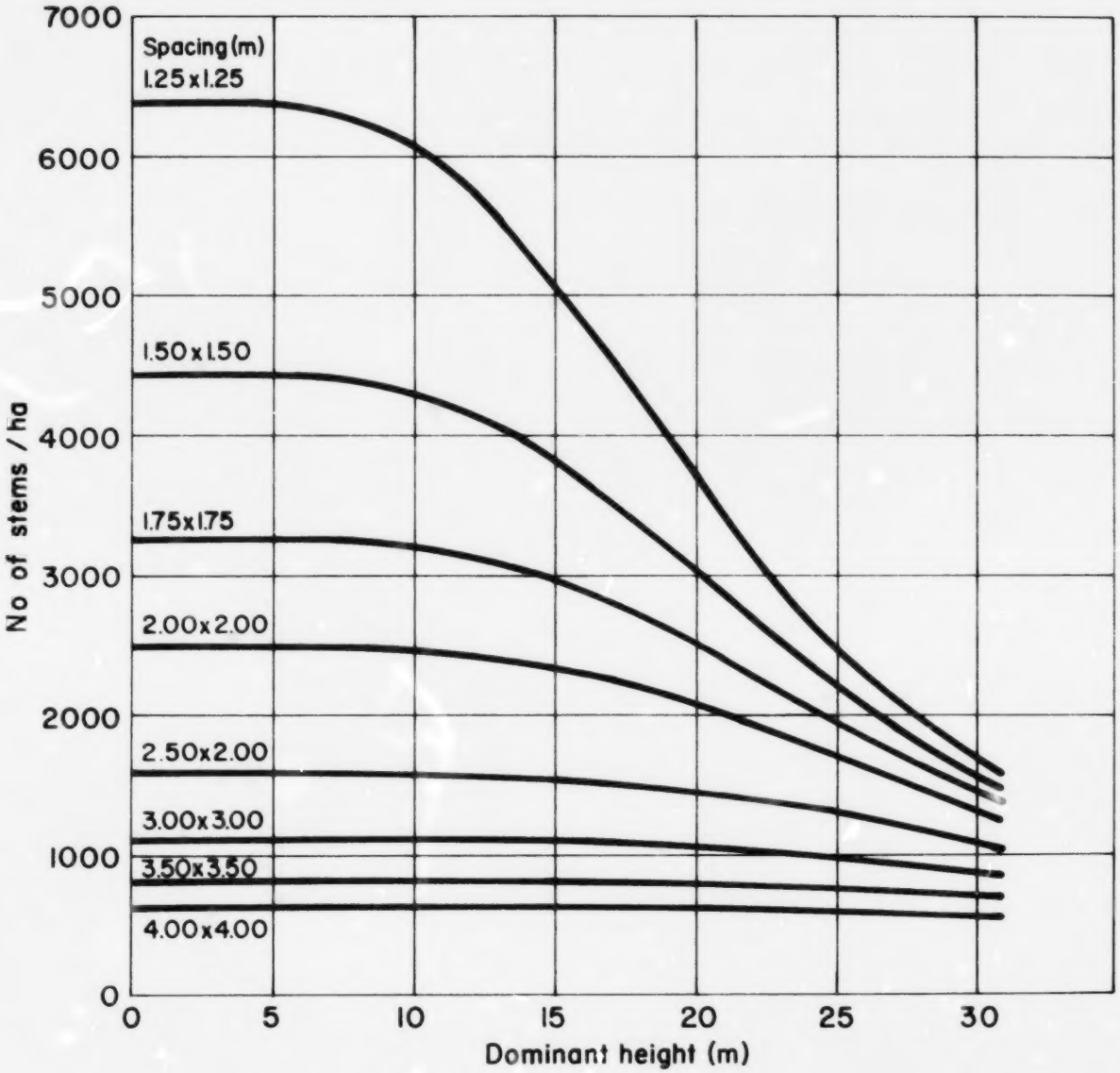

Figure 2. Relationship of numbers of trees to dominant height and initial spacing for planted red pine.

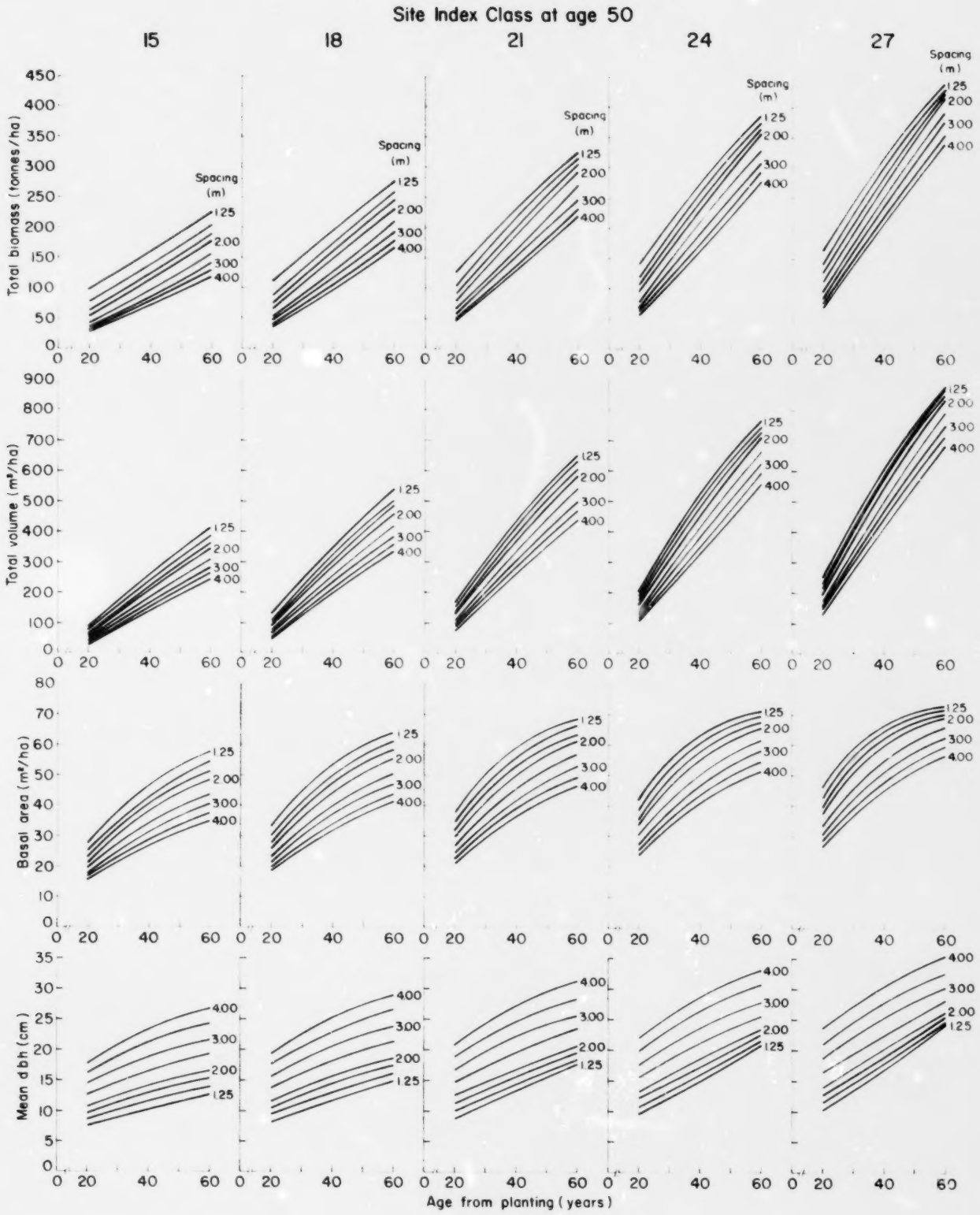

Figure 3. Diameter, basal area, total volume, and total biomass of planted red pine as affected by site index and spacing.